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CAPITAL-LABOR UTILIZATION AND SUBSTITUTION IN PUNJAB AGRICULTURE

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CONTENTS

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I. INTRODUCTION

In this paper we project capital-labor utilization and substitution patterns for Punjab agriculture to the year 1980 and display short-run capital-labor substitution relations as they existed in the years 1955, 1965 and 1970, and we project them for the year 1980. These projections and comparative statis analyses are derived from a dynamic, microeconometric simulation model of Punjab agriculture which was designed to track the actual course of development and to make possible realistic projections of its future course under alternative government policies. The model and its evaluation is completely described in DAY and SINGH [1971] and SINGH [1971]. The model's detailed description of the green revolution for the period 1952-1965 is the subject of another paper SINGH and DAY [1972]. For purposes of comparison the results described there are summarized in section II below. Then the projections to 1980 are reported in section III followed in section IV by the comparative static analyses. Our conclusions complete the paper in section V.

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II. CAPITAL-LABOR UTILIZATION AND SUBSTITUTION 1952-1965

1. The Model as an Economic History Simulator

Our Punjab model was simulated to generate literally dozens of variables describing economic activity on farms in the Punjab for the period 1952-1965. Model results for field crop acreages were compared to available series for purposes of model evaluation. Expert testimony of required experts was also used as a basis for determining goodness of fit. Having in this way determined that the model tracked recent events reasonably well it was possible to use the wealth of additional detail to obtain new quantitative estimates of regional agricultural activity during the green revolution. It is this use of the model that serves as the basis of the results now summarized. It fills in with detailed, numerical estimates the gaps in the piecemeal statistics available from other sources.

2. Labor Utilization

Annual labor use in the Punjab began to decline in 1954, then leveled off and after 1961 began to increase rather sharply. By the end of the period the total annual utilization of labor was actually above what it had been at the beginning. Annual labor use as a percentage of total labor available and annual labor as a percentage of family labor available followed exactly the same pattern. Measuring labor surplus on the basis of annual availabilities, anywhere from 36 to 52 percent of the total labor and 17 to 37 percent of the family labor was surplus or redundant in the region.

Labor utilization by season reveals quite a different picture. Labor use increased substantially for some seasonal periods. During period I when the summer crops are planted, the index increased from 100 to 166.

During period VI, when the winter crops are harvested and threshed, the index increased from 100 to 193. During period VII when winter crops are transported and land prepared for summer planting the index increased from 100 to 123. In other periods the index of use increased only moderately. In period II, when irrigation for summer crops is carried out, the index increased from 100 to 113; and during period III, when the winter crops are planted, the index increased from 100 to 123. In still other periods, however, labor use declined. During period IV when summer crops are harvested, winter crops are irrigated and sugarcane harvested and processed, the index declined from 100 to 73; during period V when winter crops need the most irrigation, the index declined from 100 to 62. Though the demand for total annual labor has increased slightly, changes in the cropping patterns and the technological mix have increased the demand for labor substantially in some periods and reduced it substantially in others.

To summarize, the model reflects a drastic structural shift in the demand for labor. Indeed, instead of a chronic labor surplus one finds a picture of seasonal scarcity. Family labor is very scarce in some periods, occasionally scarce in others, slack in some and very slack. In periods III and VI, when labor is very scarce and family labor is exhausted, labor has to be hired in order to perform all the tasks.

3. Direct Investment and Capital Utilization

Capital utilization takes a variety of specific forms. Here we focus on nonfarm-produced capital goods: tractors, tubewells, power threshers and cane crushers; and nonfarm produced variable inputs: fuel, fertilizer, irrigation water, which flow from capital goods in the nonfarm sector or from outside the country altogether. The number of tractors in use increased sevenfold, the number of tubewells in use nearly twelvefold and the number

of power threshers over fourfold, even though the latter were introduced only in 1963. The implication of these patterns was a rapid transition from the traditional man-bullock intensive technology to the modern, mechanical power intensive technology.

The most spectacular changes estimated are in the irrigation task. Total standard irrigation increased by some 39 percent, but the index of irrigation delivered by tubewells increased by 501 percent! This increase was at the expense of the traditional and costly persian-wheel irrigation whose share according to the model declined from 54.2 percent in 1952 to zero in 1961, being totally replaced by the tubewell. Although the model exagerates this phasing out (several hundreds of persian wheels are actually still in operation in 1970) the dominance of tubewells is almost complete in the region.

Farm produce transported to the market increased nearly fivefold. The index of total transportation increased by 396 percent, but the share of tractor-transportation declined slightly. This is partly explained by the fact that a large component of tractor-trailer transportation involves taking cane to the mills, and cane production did not increase quite as rapidly as the production of other crops. However, the main reason is that the replacement of wooden wheels by rubber tires on the bullock carts makes the use of bullocks released from the irrigation task for short haulage relatively inexpensive. So the share of tractor transportation in the total haulage has remained fairly constant.

4. Indirect Investment and Capital Utilization

In addition to direct flows of capital into Punjab agriculture, the increased use in off-farm variable inputs means an indirect flow of capital, since these are invariably capital intensive products. This flow is

reflected in the model estimates of fuel and fertilizer utilization in the farm sector. The use of petroleum fuels increased about fivefold during the 14 year period. The use of mitrogen increased twelvefold while phosphorous use increasing 53 times its initial level in 1952. The total acreage of all crops fertilized increased four times, the greatest percentage being in high yield varieties of wheat, hybrid maize and rice. The average nitrogen use per acre grew from 3.6 kilograms per acre in 1952 to 11.4 kilograms per acre by 1965, while the percentage of irrigated area under fertilization increased from 19.8 percent in 1951 to 55.9 percent in 1965.

5. Labor-Capital Productivity and Substitution

The capital-labor utilization patterns before us imply changing aggregate input-output ratios that give a good picture of changing input productivity and substitution. Total output doubled while the value of the marketed surplus trippled over the period. About five percent of the total increase in real output could be accounted for by an increase in the physical area brought under cultivation; another 30 percent can be accounted for by an increase in double cropping. The remaining 65 percent is due to yield increases. The "take-off" in regional agricultural development is clearly identified with 1961-1962 when the use of working capital began its steady rise signalling the massive flow of capital, direct and indirect, into the region.

The substitution of capital in the form of mechanical power for labor is reflected in the steady decline in the labor output and bullock output ratios and in the rise in the machine output ratio. Average capital productivity increased by nearly 50 percent! Over .53 rupees were required per unit of output in 1952, by 1965 only .36 rupees were required, in spite of the fact that the ratio of purchased to non-purchased inputs had increased

over the period! The land/output ratios have shown a similar decline. Cultivated acreage increased by some 5 percent while cropped acreage because of double croppings increased by some 36 percent during the period under consideration.

Capital-labor substitution is also reflected in the decrease in the bullock-labor ratio to half its 1952 level and in the steady increase in the machine-labor ratio to nearly fivefold its 1952 level! The land-labor ratio showed a steady increase from 1952 to 1961 bearing out the increased ability provided by mechanical power to crop more land. Nonetheless, the land-labor ratio declined somewhat after 1962 as a result of increased yields due to the adoption of new varieties, increased fertilization and irrigation. The working capital-labor ratio has shown a slow but steady increase totaling about 30 percent over the period. Average physical productivity nearly doubled while the value of sales per unit of labor nearly tripled.

6. Summary

The model has described the process by which decentralized decision makers, the Punjabi farmers, responding to market incentives and the growing supply of new resources, speedily converted from traditional farming practices to modern, capital intensive methods of production. This conversion was accomplished by the substitution of industrially produced capital goods such as tractors and machines, and industrially produced, capital intensive variable inputs such as fertilizer, petroleum fuels and electricity, for farm produced capital and labor.

III. PROJECTIONS FOR 1980

What does the future hold for capital-labor utilization and substitution in the Punjab? To answer this question, and to provide a basis for the

comparative static analyses to follow, we projected the various exogenous variables (population, prices, etc.) for each year 1966 to 1980, using simple trend analyses and the judgement of regional experts. We then projected the endogenous variables by simulating the recursive programming model using the independently projected exogenous variables. To provide benchmarks for comparison we report here in Table 1 our estimates for employment and resource utilization for 1955, 1965 and 1970, in addition to 1980. We shall briefly discuss the most interesting of these data.

As already noted total annual employment showed only a slight increase between 1955 and 1965, but began to decline after that. The decline in total employment projected for the decade 1970 to 1980 is 10.6 percent, a little more than one percent per annum. This decline, it should be emphasized, involves only that employment associated with <u>crop production</u>. It cannot be interpreted as a projection of <u>total</u> rural or on-farm employment. This is because these estimates do not include other farm employment opportunities offered by non-crop activities such as poultry, vegetable and dairy production, or rural nonfarm employment opportunities associated with distribution, marketing, transportation and processing industries. With the substantial increase in the total demand for nonfarm inputs and a substantial increase in total output, and a continual increase in poultry, dairy and livestock production in the region, it is possible that total rural employment in the region will increase by 1980. For such an increase to occur rural farm and nonfarm activities need to provide additional employment of 1.14 million man days per year. With an estimated agricultural labor force of about 640,000 family and wage laborers in 1970, this amounts only to 1.8 man days of work annually per laborer currently employed in farming.

Table 1: Estimated and Projected Resource Use 1955, 1965, 1970, 1980

Resources	1955	1965	1970	1980
A. Land Use (millions of acres)				
1. Area Cultivated	2.5398	2.758	3.1729	3.2489
2. Area Cropped	3.3647	4.268	4.9218	6.3709
3. Irrigated Area Cultivated	1.7568	2.082	2.7731	3.1218
4. Irrigated Area Cropped	2.4017	3.214	4.0352	5.9317
5. Area Sown to New Varieties	--	0.3042	1.8784	4.8601
B. Labor (millions of man days)				
1. Total Annual Labor	101.23	108.32	107.02	95.66
2. Total Hired Labor	3.411	4.248	5.127	--
3. Winter Harvest Labor	8.564	9.882	10.286	2.896
C. Animal Draft (millions of days)				
1. Annual Bullock Labor	50.169	29.684	25.03	5.243
D. Mechanical Power Use				
1. Tractors (millions of hours)	2.265	5.549	12.045	27.547
2. Diesels (millions of litres)	12.69	28.37	42.47	71.64
3. Electric Engines (millions KWH)	18.69	111.98	218.67	442.06
4. Total Power Use (millions BHP hours)	116.74	349.17	646.12	1317.78
E. Nutrient Use (millions of kilograms)				
1. Nitrogen	--	57.02	156.65	309.08
2. Phosphorus	--	3.88	37.13	74.04
3. Potash	--	4.84	41.22	89.56
4. Total NPK	--	65.74	234.90	472.78
F. Capital Use (millions Rs. at constant 1970 prices)				
1. Total Outlays	273.29	510.47	893.0	1653.94
2. Outlays on Variable Inputs	264.02	479.17	829.0	1491.79
3. Outlays on Non-Farm Variable Inputs	76.30	307.78	625.36	1110.42
4. Outlays on Non-Farm Invariable Goods	9.26	31.29	63.32	162.15
5. Borrowing Working Capital	273.29	415.16	619.12	605.87
6. Outlays of Nutrients	--	188.99	468.22	868.45

Further possibilities for farm employment would be achieved by a continued growth in triple and quadruple cropping of vegetables, a practice already found to be economical with careful water and nutrient management around urban areas. Such a development might very well further aggrevate the seasonal labor shortages which, as we have shown, have already been experienced for two decades. Quantitative projections of this kind would require a modification in our model, however.

Annual hired labor continued to increase between 1955 and 1970, but it is expected that by 1980 the demand for hired labor in field crop production will all but disappear. This result follows from the projected increase in the supply of family labor combined with increasing mechanization of activities performed during the labor bottleneck seasons. The main decline has been in the demand for winter harvest labor as harvesting and threshing tasks become mechanized. If, however, as has been customary, all harvesting tasks continue to be performed by hired labor only, even when family labor is available during harvest periods, about three million man days of hired labor will be demanded by 1980. This is a decline of about 4.5 percent per annum over the 1970 to 1980 decade.

If we assume, as we do in the model, that the agricultural labor force continues to increase at the same rate between 1970 to 1980 as it did in the decade 1955 to 1965 (1.65 percent per annum), then the supply of regional labor will increase faster than the demand for crop production. Total annual employment in the region will increase but seasonal labor shortages will be eliminated. This comes to pass even though the area under cultivation is increased by 76,000 acres and total cropped area by 1.45 million acres. Thus in the decade 1970 to 1980 the agricultural sector, which has been an <u>apparent</u> labor surplus economy, will be transformed into an <u>actual</u> labor surplus economy, a result which ironically will be

brought about by the final elimination of the traditional, agrarian economy.

The decline in animal draft will continue. Indeed, animal power will be virtually eliminated as tractors, diesel engines and electric motors replace the ox and camel. The increasing pace of mechanization will be accompanied by the overwhelming adoption of yield increasing technology as evidenced by the increase in the area sown to new varieties from 304 thousand acres in 1965 to 4.86 million acres in 1980 (82 percent of the total irrigated area cropped) and the increase in the use of chemical nutrients from 65.7 million kilograms in 1965 to 472.8 million kilograms by 1980. Total capital outlays will increase to 1,654 million rupees at constant 1970 prices.

These substantial structural changes will be accompanied by a 70 percent increase in total output, an 85 percent increase in market sales between 1970 and 1980 (valued at constant 1970 prices) and a decline in subsistence production from 52.6 percent in 1955 to 10.2 percent by 1980. These figures are shown in Table 2 which also contains various input-output and input-input ratios. The substitution of capital for labor is projected to continue as, for example, machines hours and the total working capital expended per man day are expected to more than double in the present decade! The output per unit of labor doubled between 1965 to 1970 and will very likely double again between 1970 and 1980. By 1980 it will probably be six times its value in 1955. A similar pattern is observed for land productivity, though the productivity will inevitably decline as 1980 approaches and the opportunities for spectacularly profitable investments taper off.

Table 2: Estimated and Projected Output, Factor Productivities and Factor Proportions 1955, 1965, 1970, 1980

Item	1955	1965	1970	1980
(in millions of Rs. at 1970 prices)				
1. Total Output	1563.91	2729.94	5089.79	8703.38
2. Market Sales	741.23	1859.3	4211.55	7816.97
3. Subsistence Production	822.68	870.41	878.25	886.41
4. Degree of Subsistence (3) ÷ (1)	52.6%	31.88%	17.26%	10.18%
Factor Productivity				
1. Labor (Rs./man day)	15.45	25.20	47.56	91.00
2. Land (Rs./acre)				
Per Cultivated Acre	615.76	989.82	1604.14	2678.87
Per Cropped Acre	464.80	639.63	1034.13	1366.11
3. Capital (Rs./Rs.)	5.72	5.35	5.70	5.26
(at constant 1970 prices)				
Inputs Per Acre (per cropped acre)				
1. Labor (man days)	30.09	25.38	21.74	15.02
2. Animal Draft (days)	14.91	6.96	5.09	0.82
3. Tractor Use (hours)	0.67	1.30	2.45	4.32
4. Diesel Use (litres)	3.77	6.65	8.63	11.24
5. Electricity (KWH)	5.55	26.24	44.43	69.39
6. Mechanical Power (BHP hours)	34.69	81.81	131.28	206.85
7. Working Capital (Rs.)	78.47	112.27	168.57	234.16
Inputs Per Unit of Labor (per man day)				
1. Animal Draft (days)	0.496	0.274	0.14	0.055
2. Mechanical Power (BHP hours)	1.15	3.22	6.04	13.76
3. Land (cultivated acres)	0.0251	0.0255	0.0296	0.034
4. Working Capital (rs.)	2.61	4.42	7.75	15.59
5. Outlays on Non-Farm Variable Inputs (Rs.)	0.75	2.84	5.84	11.61
Total Capital Use (in constant 1970 Rs.)				
1. Per Cultivated Acre	107.60	185.09	281.44	509.08
2. Per Cropped Acre	81.22	119.60	181.44	259.61
3. Per Man Day	2.70	4.71	8.34	17.29
4. Per Unit of Output	0.1747	0.107	0.1754	0.19

Continued

Table 2: Continued

Items	1955	1965	1970	1980
Outlays on Variable Non-Farm Inputs*				
(in constant 1970 Rs.)				
1. Per Cultivated Acre	30.04	111.59	197.09	341.78
2. Per Cropped Acre	22.68	72.11	127.06	174.29
3. Per Man Day	0.754	2.84	5.84	11.61
4. Per Unit of Output	0.0468	0.1127	0.1229	0.1275
5. % of Total Capital Use				
Average Yields (in kilograms per acre)				
1. Wheat	440.5	951.0	1800.0	2224.0
2. Gram	491.0	486.0	500.0	449.0
3. Cotton (D)	100.0	101.0	102.0	102.0
4. Cotton (A)	150.0	223.0	243.0	243.0
5. Maize	584.0	958.0	1231.0	1795.0
6. Rice	493.0	504.0	1011.0	2027.0
7. Sugarcane	117.35	204.96	2455.0	2455.0
8. Groundnut	311.0	239.0	239.0	239.0
9. Bajra (Millets)	378.0	211.0	315.0	609.0
10. Total NPK Use (kilograms per irrigated cropped acre)	--	20.45	58.21	79.7
Water Use (in std. irrigations)**				
1. Per Cultivated Acre	6.43	7.99	9.92	14.91
2. Per Cropped Acre	4.86	5.16	6.39	7.60

*Outlays on fuel, oil, repair and maintenance, electricity, nutrients and canal water.

**Defined as 3 acre inches of irrigation water.

IV. COMPARATIVE STATIC ANALYSES FOR 1955, 1965, 1970, 1980

So far in our discussion we have emphasized the process of agricultural development as we have understood it to have occurred and as we have projected its likely future course to the end of the present decade. We have focussed on the time-consuming process of change, showing how agriculture in the Punjab has adjusted and on the basis of current information how it is likely to adjust to economic opportunities created by new technology,

market incentives, and expanding supplies of nonfarm inputs.

In this section we change our focus to an analysis of the short-run possibilities for resource substitution and reallocation in response to independently varied parameters. Five individual comparative static or parametric programming analyses have been performed for the years 1955, 1965, 1970 and 1980 using as a base in each case the situation estimated or projected by the dynamic model for the given year. The analyses involve changes in labor, investment goods and credit supplies and costs.

1. The Marginal Efficiency of Capital

Our first exercise in comparative statistics was to vary the supply of working capital, beginning with the amount estimated for the base year, to obtain the corresponding shadow price, or internal rates of return at various capital supplies, in this way tracing out the marginal efficiency of capital schedule for a given year. The schedules obtained are displayed graphically in Figure 1.

These derived demand curves for capital shift substantially over time. Though the rate of return to liquidity at the initial margin is low being determined by the opportunity cost of borrowing working capital it rises very rapidly, going as high as 700 to 800 percent when liquidity is reduced by half. The schedules rise more steeply in the earlier years (1955, 1965) than in the latter years (1970, 1980), suggesting that over time the demand for liquidity has become and will become still more elastic. This is no doubt due to the fact that especially after 1970 the marginal return from yield increasing inputs is quite low and increments of these inputs bring about smaller and smaller increases in output.

2. The Derived Demand for Nonfarm Capital Goods

The next exercise was to explore the possibility that investment in

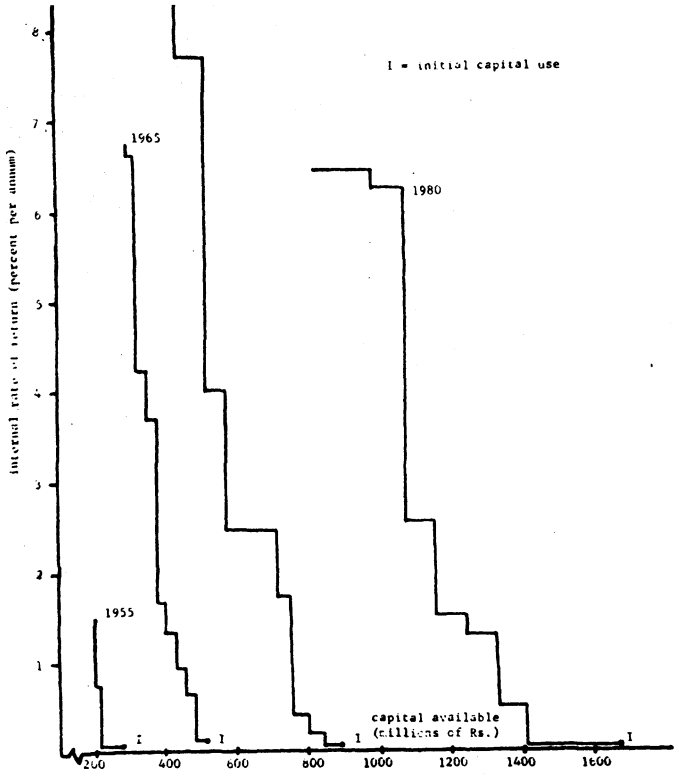

FIGURE 1: MARGINAL EFFICIENCY OF CAPITAL

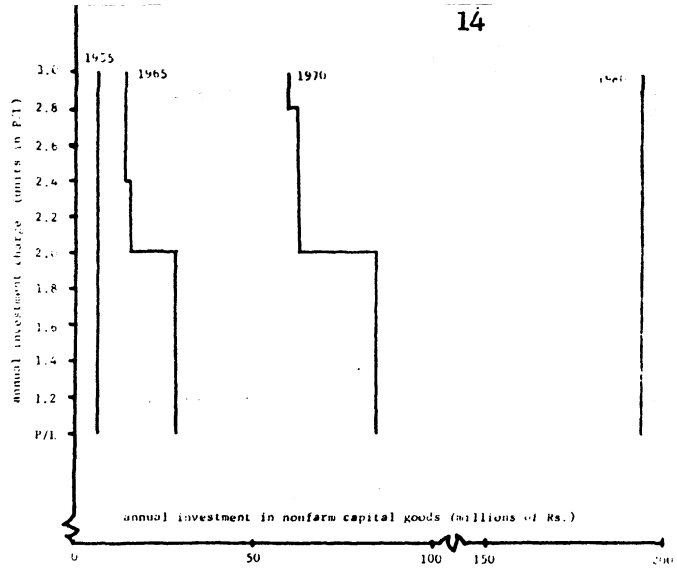

FIGURE 2: DERIVED AGGREGATE DEMAND FOR NONFARM CAPITAL GOODS

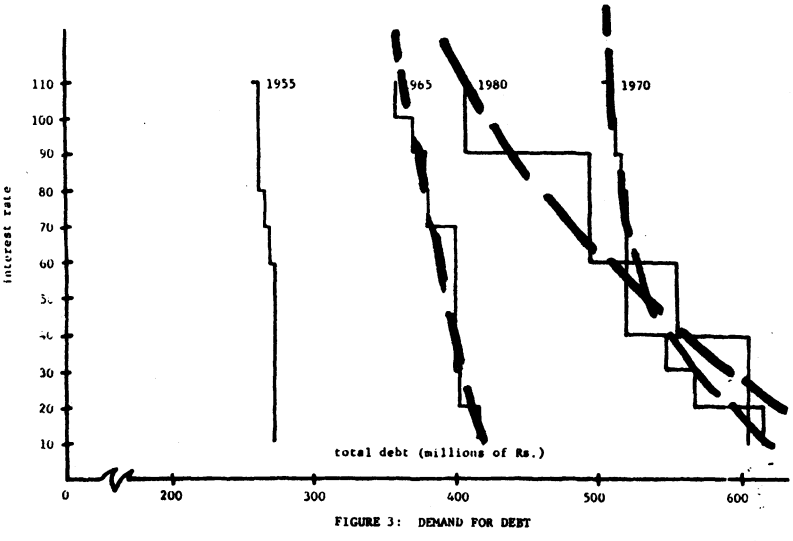

FIGURE 3: DEMAND FOR DEBT

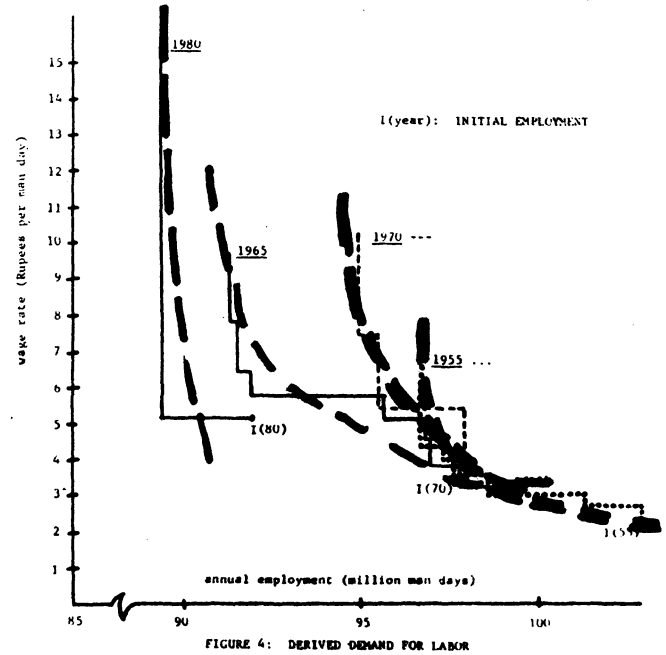

FIGURE 4: DERIVED DEMAND FOR LABOR

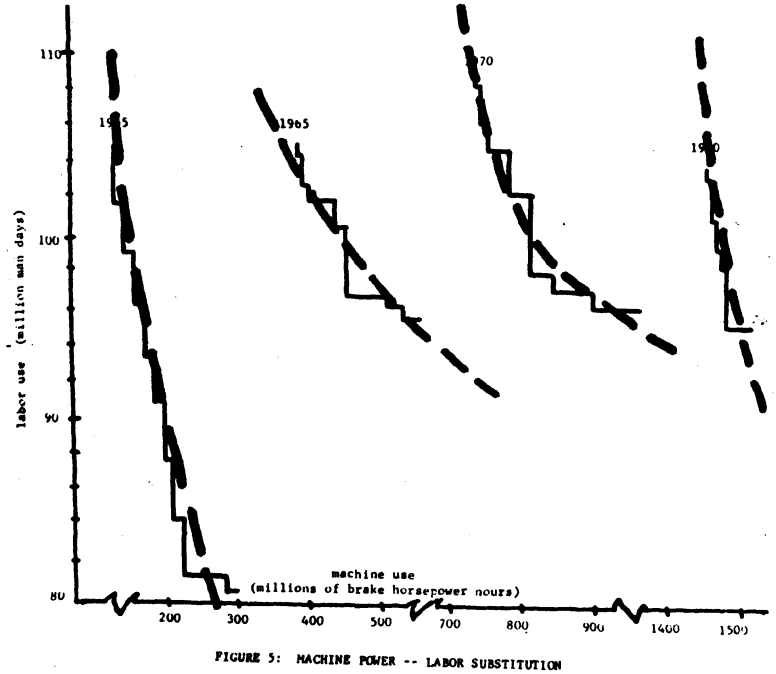

FIGURE 5: MACHINE POWER -- LABOR SUBSTITUTION

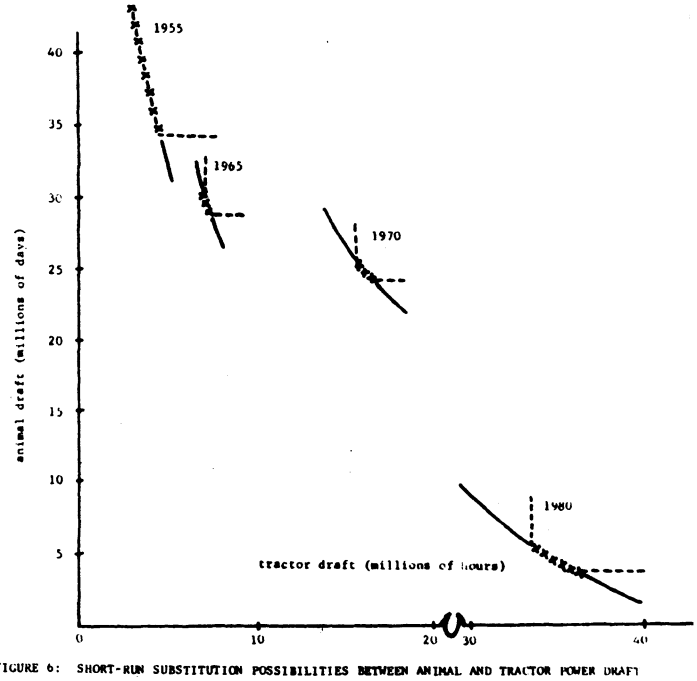

FIGURE 6: SHORT-RUN SUBSTITUTION POSSIBILITIES BETWEEN ANIMAL AND TRACTOR POWER DRAFT

mechanical power and machinery was influenced by factor price distortions in favor of capital inputs. This was accomplished by varying the annual investment charges or depreciation allowances from their initial levels to three times that amount. The result is a derived demand curve for each capital good. These were aggregated by using 1970 constant prices. The resulting figures trace out derived demand curves for aggregate nonfarm capital goods in each year. They are displayed in Figure 2.

The extreme inelasticity of these schedules is evident, though in the middle years a doubling of farm machinery prices would have caused a substantial drop in annual capital investment. New power sources and machines are in fact highly cost effective. They replace hired labor, relieve seasonal labor shortage and release land from fodder production for bullocks making possible its allocation to high yielding new varieties.

3. Demand for Debt

Debt is an important means of financing farm expenditures in Punjab agriculture. In our treatment all debt is assumed to be refinanced each year so that the borrowing activity for each year reflects the total demand for debt under existing economic conditions. Because previous debt must be maintained -- at least to the extent it cannot be retired -- the demand for debt over the period considered becomes inelastic at some interest rate. Below this rate the demand for loanable funds does respond in a few discrete steps to reductions in interest. By varying the interest rate this demand for loanable funds can be traced out.

Figure 3 shows these derived demand for indebtedness curves for each of the four years. As the sector becomes more commercialized, that is, as it becomes more intimately linked to the market economy the elasticity of demand for loanable funds increases. The large discrete steps may be

expected to be much smoother in reality, so that the large inelastic segments might be expected to be broken down into a series of shorter steps.

4. The Derived Demand for Labor

A large proportion of the employment in the farm sector is accounted for by the use of family labor as shown by the results discussed in Part III. Only a small percentage of labor is hired (3-4 percent in 1955 to 1970, none in 1980) and that only for the peak periods in April and October-November. Therefore the main question of the impact of changing labor costs revolves around the opportunity cost assigned to the use of family labor.

The results in Part III are based on the assumption that family labor is a fixed farm resource in the short-run, and therefore it has a zero opportunity cost to the farmers. Subsistence consumption constraints in the model are used explicitly to take account of the food requirements of this labor force in terms of food grains produced on the farm. The outputs that are retained cannot then be sold on the markets and hence are the fixed costs of maintaining the family labor force. On the basis of a zero opportunity cost for family labor, with hired labor at the going wage rates, we estimated regional farm employment of 107.8, 108.3, 107.0 and 95.7 million man days respectively for 1955, 1965, 1970 and 1980.

We examine now the impact of increasing the opportunity cost of family labor and of hired labor as well. We first give family labor a wage equal to half the going local rate and regional (non-local) labor a rate half again as high as the local rate. We then vary these rates continuously. This parametric programming exercise then traces out derived demand curves for labor, one for each year, as shown in Figure 4.

As a first point of interest we note that as the opportunity cost of family labor is increased from zero to fifty percent of the market wage, total employment falls to 103.0, 99.1, 98.1, and 92.6 million respectively for 1955, 1965, 1970 and 1980 (marked by the letter I on the graph to indicate the initial solution). These declines amount to 4.5 percent, 8.5 percent, 8.4 percent and 3.3 percent in total employment from the level of employment at a zero opportunity cost for 1955, 1965, 1970 and 1980 respectively. The demand for labor is fairly inelastic for all the four years, though relatively less inelastic for 1965 and 1970 in this range.

The drastic decline in the dervied demand for labor after 1970 is expected from our earlier historical analysis and projections to 1980. Quite unexpected, however, is the shift in the general slope of the curve especially for the year 1965 a period in which changes in wage rates would have had quite a substantial effect on labor use. The demand for labor actually rose in 1970, a period when high yielding varieties have already reached the most dramatic part of their impact, but in which mechanization of the labor intensive harvesting activities has only just begun.

The demand for labor in 1980 is extremely inelastic. By that time there will be left only a very small margin for labor displacement, at least on the basis of the present (1971) state of technology. This is because by 1980 most of the existing and known mechanical technologies will have been fully adopted and only new mechanical technologies such as mechanical harvesters, weeders and larger sized tractors could still further reduce the demand for labor.

To fully understand the prospects for farm employment these demand figures should be considered in conjunction with the labor supply. This

supply has been increasing, and as the figures in the following table show, this has meant increasing underemployment in the farm sector. But this underemployment is on an annual basis and does not account for seasonal shortages that persisted into 1970. As we have already noted labor by 1980 is truly surplus in all periods. Moreover on an annual basis a third of it is expected to be underemployed.

Table 3: The Demand Supply, and Underemployment of Labor

	1955	1965	1970	1980
1. Total Labor Force (estimated)* (Million man days)	187.8	220.62	238.56	275.6
2. Total Annual Employment** (Million man days)	107.84	108.32	107.02	95.66
3. Annual Under-employment (1-2) ÷ 1	42.6%	50.9%	55.2%	65.3%

*Family and regional hired labor available for 365 days.

**From Table 1 -- i.e., the total demand with zero opportunity cost for family labor.

Any conclusions based on these estimates, however, should be tempered by the qualifications pointed out above, namely, that new development in poultry, dairy and vegetable farming and local processing, transportation and correlated services will provide increased employment opportunities and will offset at least partially the drastic decline in demand for labor in field crop production.

5. Capital-Labor Substitution

Labor-capital substitution as it could have occurred and as it might in the future occur is estimated by decreasing the supply of labor and at the

same time relaxing the annual constraints on investment. The curves in Figure 5 display the substitution possibilities between the flow of machine services measured in brake horsepower (BHP) hours and labor use in man days.

The results indicate that the elasticity of substitution of labor for mechanical power sources is low for 1955, 1965 and 1970 (lying in the range 3/5 to 3/7 for the range of the data), but is relatively high for 1980. Thus in 1980 a 5 percent decrease in machine use is projected to increase annual labor use by approximately 9 percent in the range of the data analyzed, while in 1955 and 1970 a 5 percent decrease in machine use results in only a 3 percent increase in labor use and in 1965 only a 2.5 percent increase in labor use. This no doubt is mainly due to the fact that by 1980 the absorptive capacity of the sector for new power sources and capital investments is exhausted as capital saturation occurs and available mechanical technologies are fully adopted.

From the point of view of on-farm employment, however, the results indicate that even by 1980 the minimum labor demand is unlikely to fall below 95 million man days or exceed 108 million man days, for beyond these ranges only large increases in machine use are likely to bring any reduction in labor use, while further increased in labor use are unlikely to reduce the demand for machine services. The range of short-run substitution possibilities is therefore fairly small given the current profitability and availability of capital goods.

6. Substitution Between Labor Intensive and Capital Intensive Power

A further exploration of the effects of short run rigidities in capital labor substitution was obtained by parametrically varying the investment constraints for tractors and related implements in a way that would account for increases in the supply of machines and/or increases in the willingness

of farmers to adjust in the short run to profitable investment opportunities. Part of the results of this comparative static exercise are shown in Figure 6 which gives the ranges of substitution possibilities in each year between land-labor intensive bullock power and capital intensive tractor power.

Over time the substitution possibilities have become more elastic, though the range over which it can occur is quite limited in any given year -- as indicated by the dotted lines on the graph.

The largest range of actual substitution possibilities existed in 1955 where a substantial drop in the use of animal draft power is registered for small increases in the use of new power sources. By 1980 the shape has reversed itself. Substantial increases in the use of new power sources is required in order to reduce animal draft use by small amounts.

The short-run rigidity in the substitution possibilities is caused in the model by two separate structures. First the model includes adaptive bounds on various crop acreages to represent farmers' strategies to protect themselves from risk and uncertainty by preventing large changes in the cropping patterns in any given year. These behavioral constraints also have the effect of preventing large changes in factor proportions.

Second, we recall that the Punjab economy has been in transition. Not all tasks have been mechanized, and at a given time no alternatives exist to the use of animal draft for certain tasks. In this hybrid environment some tasks can be mechanized, but others can be performed only by traditional technologies. Thus short-run substitution possibilities are substantially limited. In the absence of these short-run rigidities we would expect the substitution curves to lie along the solid lines shown.

V. CONCLUSIONS

Let us review our findings. We summarize first the descriptive results, then the results of the projections and finally the conclusions following from the comparative static analyses.

Annual labor utilization declined slightly and then, as crop yields rose drastically, increased until by 1965 it actually exceeded the 1952 amount. On this annual basis the region was a labor surplus economy with between 20 to 35 percent of the family labor force unemployed. The seasonal pattern of demand shifted as mechanization of certain specific tasks occurred. In the April 16 to 30 period, demand for labor nearly doubled while in the month preceding, it fell by 40 percent. Family labor was scarce even in 1952 in three specific seasonal periods. Mechanization alleviated this family labor shortage in one period but because it did not occur in harvesting activities it was aggrevated in the peak harvest and transporting season as crop yields rose. In short, we find an economy with seasonal labor scarcities and we find in development an architect of drastic structural change in the seasonal distribution of labor demand.

Direct investment occurred in tractors, implements, tubewells and, toward the end of the 1952 to 1965 period, in threshers. Indirect investment in capital intensive inputs occurred as farm purchases of fuel, electricity, irrigation water and chemical fertilizers increased apace. All of this brought about a rapid transition from traditional farm practices to those of a modern, capital intensive, commercialized sector. This transition was uneven rather than balanced with mechanization occurring first in one task, then another. The tasks that were still dominated by traditional modes were harvesting and transporting crops to market, the mechanization of which may be expected to have great effects on

labor demand and productivity in the region.

Indeed, instead of a continued rise in labor demand we project to 1980 a ten percent reduction in labor demand for field crop production, a decline that could be offset by further developments in labor intensive vegetable, poultry and dairy enterprises. Most of the projected decline occurs in the harvest season as harvesting and transportation are increasingly mechanized. A still greater decline in labor demand is possible if larger size tractors and related equipment enter the picture, and as new technology for interculture is perfected. As it is we project the existence, at least in field crop production, of a true labor surplus economy by 1980, a result of modernization, not a characteristic of the traditional sector.

The supply of marketable surplus will grow along with the dependence on nonfarm inputs. By 1980 the Punjab will be thoroughly commercialized and the traditional sector will have all but disappeared.

The model simulation of the past two decades of agricultural history and its projection of the next decade of development can be conveniently summarized by references to three Rostovian stages of growth. These are:

I. The pre-green revolution stage prior to 1955;

II. The transition and take-off between 1955 to 1965 when the traditional agriculture was broken down and rapid growth in modern technology was established;

III. The drive to maturity after 1965 when the transition to modern, capital intensive agriculture will be completed.

These stages may be expected to be followed by a fourth stage during which the Punjab economy achieves the productivity levels, the farm practices and the agricultural problems of an advanced, developed economy.

The comparative static exercises show that substitution of capital for land and labor could have taken place somewhat faster (or slower) than

it did under appropriate changes in market conditions. However, the short run substitution possibilities were circumscribed both by technological rigidities and behavioral friction. Nonetheless, over time the longer run substitution effects were and are projected to be drastic, something revealed in the shifts of the derived demand for capital and labor and in the curve of capital-labor substitution. These results bring into stark relief the massive structural change in Punjab agriculture still in the process of becoming.

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